Research Directions in Remote Detection of Covert Tactical Adversarial Intent of Individuals in Asymmetric Operations

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***Abstract** - This article designs a first-order road map for modeling research to bridge the scientific gap between observations from physical sensor networks at 3–50 m on the one hand and determination of covert tactical adversarial intent of individuals with deception and in extensive clutter on the other. To be successful, the research needs to integrate kinesiological, neurophysiological, psychological, and cognitive science, and sociocultural anthropology and information science components. Research and development (R&D) issues that need to be considered include metrics for cognitive phenomena and how well detection systems work, data sets, determining whether actors can provide sufficient verisimilitude to create data sets, and relevant sensing technologies and information fusion techniques. Successful procedures may need to include actively (but unobtrusively) perturbing the situation in which the sensing takes place in order to elicit specific responses. Comprehensive government R&D programs are required to promote rapid progress.*

Keywords: adversarial, asymmetric, cognitive, covert, detection, individual, intent, remote, physical sensing.

1 Introduction

The ability to identify covert intent of individuals who may be hostile would significantly improve asymmetric counter-insurgency and peace-keeping operations. Such individuals are generally embedded in extensive “clutter” of neutral and friendly human beings and various physical objects. At present, covert adversarial intention is identified through judgment of soldiers and close-range sensing and searching, which often entail significant danger and possibly high false-positive and false-negative rates. Determining covert adversarial intent will help shift the balance in operations, mission planning, training, and simulation from more costly and dangerous sweeping operations toward much safer pinpoint operations based on refined estimates of people from which danger may come. Dual-use civilian benefits will be in crowd control and antidrug, anticrime, and immigration enforcement.

It has been known since the Facial Action Coding System (FACS) created by Ekman and Friesen [1] that the expression and micro-expression of certain emotions related to adversarial intent take place partially involuntarily through facial muscles. Other physiological actions such as speech, heart rate, respiration rate, skin temperature, and perspiration can also carry information

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14. ABSTRACT
This article designs a first-order road map for modeling research to bridge the scientific gap between observations from physical sensor networks at 3?50 m on the one hand and determination of covert tactical adversarial intent of individuals with deception and in extensive clutter on the other. To be successful, the research needs to integrate kinesiological neurophysiological, psychological, and cognitive science and sociocultural anthropology and information science components. Research and development (R&D) issues that need to be considered include metrics for cognitive phenomena and how well detection systems work, data sets, determining whether actors can provide sufficient verisimilitude to create data sets, and relevant sensing technologies and information fusion techniques. Successful procedures may need to include actively (but unobtrusively) perturbing the situation in which the sensing takes place in order to elicit specific responses. Comprehensive government R&D programs are required to promote rapid progress.

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about emotions related to intent, although they are more subject to environmental influence than facial expressions. Laser methods can detect muscle movement, heart, and respiration rate and skin temperature. Visual sensors provide information about facial and body dynamics. Computer vision techniques can now automatically track facial expressions, eye movement, and gestures. The ability to fuse information, for example, laser information with visual information, and to identify seemingly hidden patterns is increasing rapidly. Many of these techniques require close-range sensing/observation, often in a controlled environment and at the 0–2-m range. This is suitable for airport screening but not appropriate for asymmetric defense scenarios, where threats need to be detected at 3 m and, preferably, up to 50 m. To what extent close-range sensing techniques can be extended to longer ranges is not yet known. Moreover, modeling of the connection between emotions and intent is quite incomplete. Detecting that a person is afraid, for example, does not provide significant evidence for or against a hypothesis that the person has adversarial intent, since both friendly and adversarial people often have fear in commonly encountered scenarios. Conversely, a person with adversarial intent may show little or no fear. While there is some understanding about how to detect emotions, there is much less understanding about how to go further into the cognitive realm and determine intent.

The fundamental principles that allow remote (that is, at 3–50 m) identification of covert adversarial intent based on externally observable physical information are not known. Indeed, the step from recognizing physical objects, events, and patterns to recognizing intent is fairly described as a scientific chasm. Recent basic research related to bridging this chasm includes, but is not limited to, “Future Attribute Screening Technology (FAST)” (Department of Homeland Security—DHS), “Violent Intent Modeling and Simulation” (VIMS) (DHS), “Detection of Intent through Perception of Biomotion Signatures” and “Visualization of Belief Systems” (U.S. Army Research Laboratory Human Research and Engineering Directorate—ARL/HRED), “Remote and Passive ID of Electrodermal Response” (Night Vision and Electronic Sensors Directorate—NVESD), “Behavioral Signatures” and “Human MASINT” (U.S. Air Force Research Laboratory—AFRL), “Hostile Intent” (U.S. Naval Research Laboratory—NRL), “Computational Modeling of Adversary Attitudes and Behaviors” (Air Force Office of Scientific Research—AFOSR, George Mason University), “Dynamic, Adaptive Techniques for Adversary Behavior Modeling” (AFOSR, University of Maryland), “Human, Social, Cultural, and Behavioral Modeling” (U.S. Army Research Office—ARO, Carnegie Mellon University, University of Maryland), “Tools for Recognizing Unconscious Signals of Trustworthiness Program (TRUST)” (Intelligence Advanced Research Projects Activity—IARPA), and HERMES, a computer vision system for analyzing human behavior (Universitat Autonoma de Barcelona, http://www.eurekalert.org /pub_releases /2010-01/uadb-hnc011310.php).

In this article, we provide a first-order road map for modeling research to bridge the scientific gap between observations from physical sensor networks at 3– 50 m on the one hand and determination of covert tactical adversarial intent of individuals with deception and in extensive clutter on the other. Although empirical observations and experiments will play large supporting roles in this research, the main emphasis is on discovery of theoretically justified quantitative predictive principles (models) and their implementation in tractable analytical and computational procedures. To be successful, the research needs to integrate kinesiological, neurophysiological, psychological, and cognitive science, and sociocultural anthropology and information science components.

This paper is based on an ARL special report [2] written shortly after the ARL Strategic Directions Workshop “Remote Detection of Covert Tactical Adversarial Intent of Individuals in Asymmetric Operations” at ARL in Adelphi, MD, on December 7 and 8, 2009. These documents describe directions of research that the participating agencies deem worthy to pursue in the near future. There are many related directions of research of interest to the participating agencies and many other agencies, including, but not limited to, close-range or contact techniques (e.g., for airport security or semicooperative screening), physical pattern recognition, behavior modeling, predictive modeling (“What will that organization/group/person do next?”), information from non-physics-based sensors/sources (human reports, media, databases, data mining, learning, World Wide Web, game theory, etc.), cultural dependence, etc. Research that is described here will be influenced by and will influence research in these other areas, which are important in their own right. However, to retain focus, this article does not treat these other areas.

Throughout this paper, the phrase “remote detection of adversarial intent” will mean “remote (at 3–50 m) detection of covert tactical adversarial intent of individuals in asymmetric operations.”

2 The Current Situation and the Future

In the early part of the 21st century, we are in the middle of “asymmetric warfare.” Asymmetric warfare, i.e., armed conflict between a nation and often faceless, nameless individuals, and organizations that are not affiliated with any government, has occurred throughout human history but has recently become more prevalent.

Over the past two decades, warfare has shifted from traditional warfare (i.e., wars of fire and maneuver characterized by large force-on-force actions) to asymmetric warfare (i.e., wars of insurgency) due to many factors, including, but not limited to, the occurrence of foreign actions in the U.S. homeland and to operations in

Afghanistan and Iraq. There is a need to find individuals who are hiding in civilian populations and remove them without causing collateral damage. In order to find these individuals, it is necessary to determine their intent.

The concept "intent" is widely used in the signal processing literature for "a physical pattern that (in a layman's view) allows a conclusion of intent." However, the number of false positives and false negatives produced when intent is interpreted as "a physical pattern" is large. Physical states such as sweating are also poor indicators of intent. In this paper, intent is a concept with cognitive content that does not need to coincide with the seemingly obvious physical patterns or states often connected by non-specialists with intent. The step from fused physics-based information to a conclusion of cognitive intent is huge. In this process, physical patterns and states may not individually be indicative of intent. However, by proceeding from the physical patterns and states through a fusion process that will put "orthogonal" signals together based on cognitive principles, intent can be determined.

Humans who are intending to carry out preplanned violence have usually been coached and prepared in a manner not common to daily life. Historical data on World War II kamikaze pilots may be relevant to these considerations. Differentiable commonalities may exist in schooling and feelings of kinship. Just knowing one's task and fate can have consequences in biological motion, especially if the violence is technologically enabled (e.g., triggered bomb vest). There is evidence that observers watching video clips on closed-circuit television can reliably detect individuals carrying weapons by judging that these individuals appear to have higher levels of malaise and restlessness [5].

This article focuses on remote detection of covert tactical adversarial intent of individuals in asymmetric operations. In future operations, this topic will, of course, be embedded in a larger framework that will include use of information from databases, media, human sources, and other non-physics-based sources, which can operate at long distances (greater than 50 m) and long time scales (hours, days, months). However, given the paucity of knowledge in this area, it is preferable to start from research that involves only physics-based sensors and medium distances (3–50 m).

A multitude of potentially fruitful research directions is discussed in the next section. These directions indicate that it is fair to estimate that remote detection of adversarial intent is indeed feasible. Success, however, will depend on the details of how the already existing building blocks plus new building blocks can be put together.

3 Research and Development Directions

Our objective here is to describe R&D directions that will eventually bridge the gap between physical phenomena and cognitive intent using scientifically-based (rather than layman's-experience-based) principles. Given the paucity of knowledge in the area, we cannot always demand well-established principles. Hypothesized principles may have to be used when established principles are unavailable.

3.1 Cognitive/Perceptual Phenomena

In research on sensing adversarial intent, a basic assumption is that every brain action or state has a corresponding effect or state, however diminutive or hidden, in the body and that the effect or state in the body is amenable to some sort of sensing, even if not remote. Can quantitative connections between cognitive states and detectable signals be identified? Is passive observation sufficient or is it useful/necessary to actively (but unobtrusively) introduce signals/perturbations in the observation process to gather sufficient information? "Active elicitation" of information may be a fruitful area for research.

One should note that superficial "profiling" seems to fail. The Transportation Security Agency (TSA) has noted that random screening produces more valid "hits" than superficial profiling. However, this experience may not be applicable without caveats to many defense situations. Can cognitive state be quantified and quantitatively related to detectable signals, or is this even needed? Is physiological state enough to determine that a person is "anomalous" and has an adversarial "plan?"

What are the effects of people who are actually innocent bystanders but have knowledge that can potentially jeopardize them and their family? Can research be done on bystanders? What are the cues that a bystander gives off if he or she knows something about a plan? Are these cues detected by "expert human detectors?" Can these cues be automatically detected by sensors?

Exploration of enemy tactics, techniques, and procedures as contextual factors for determining intent should be considered. Most individuals intending to do harm have gone through at least some type of training and practice. There is often a need to actively induce or ramp-up a response from individuals so that it can be sensed. By actively inducing a response, the flow of a plan will be altered and perhaps more easily observable. Those who have a plan may be affected more by even normal delays than others. People with a plan may get increasingly angry with delays, whereas others may just have ordinary annoyance but not anger. The TSA SPOT program is investigating such issues.

After the beginning of a stimulus, physiological cues in some/many processes can peak in 5–10 s. The human body tends to have many non-specific responses (i.e., physiological responses that are part of the homeostatic or other internal state of the body unrelated to external cognitive stimuli). In order to understand which physiological cues relate to which stimulus, it is necessary to know the timing of the stimulus. Can a person's cognitive load be probed in time? If so, these probes need to be culturally appropriate and relatively inconspicuous. How and when can previously rehearsed patterns be perturbed? It will be important to develop good stimuli for evoking a response that might be an idealized adversarial intent cognitive state, emotion, or arousal level. There may be differences due to different situations. Those carrying bomb vests implying self-immolation can have a different cognitive set (with associated biomarkers) than those controlling remotely triggered explosive devices. Research about how one actively (and unobtrusively) controls the situation so that threat indicators are likely to be expressed and thereby achieves subject engagement and behavioral authenticity is needed. Given the enormity of the topic and its currently amorphous state, perhaps an iterative approach to experimentation, in which scenarios are initially kept relatively simplistic and then experimental complexity is increased as knowledge is gained, is best.

Research on states of mind related to the timing of the event can be beneficial. For example, if an act and the associated verbiage to be used if interrogated have been well rehearsed, then there might still be some variability in responses up until very close to the act. At that point, there could be a reduction in normal physiological responsiveness but more of a response to an unexpected event delaying the plan. Research related to planning and disruption to plans might be helpful to distinguish the effect of the type of plan on the response to disruption or delay. Much of what may have to be done, without the benefit of an interview/interrogation, is to induce a response. This response can be cognitive or behavioral and will be biased by cultural constructs. Stimulus-response operational design in a complete theoretical framework is likely to be advantageous. However, the likely difficulty in constructing a suitable theoretical framework suggests that beginning with an empirical and observational approach may be advisable.

Differentiation needs to be made between psychological issues (ideologues, disaffected, etc.) and psychopathological issues (not sociopathic). Clinical data may not be applicable as physiological indicators. For example, sociopaths may be emotionally numb. Further, there could be possible links to religious fanaticism and the associated training involved (cf., for example, the El Alamut Assassins http://www.alamut.com/subj/ideologies/alamut/secDoctrines.html). Can we identify the different types of terrorist psychologies? Are there significant differences between the person who totally believes he or she is carrying out an important duty vs. the person who has been forced into compliance with the plan through threats and intimidation?

Another important and often overlooked concept is measuring the problem. Metrics for cognitive phenomena and for how well detection systems work are needed. The metrics themselves may be computationally intensive but should run seamlessly in the background, invisible to the user. Results should be easily interpretable and not lend themselves to a "so what" response by the user. Often, new metrics are developed in conjunction with user communities, which usually ensures that such metrics are practically useful. In addition to being practically useful, however, the metrics need to be computationally feasible (not combinatorially expensive) and mathematically justified. Whatever metrics are proposed should be justified not based on traditional use of the metrics in other areas, successful as that use may be, but rather on the basis of human goals in the remote detection of covert tactical adversarial intent. In the past, metrics based on information theory have been recommended for use in the fusion process. Information-theoretic metrics were designed for non-biological physical processes. Evidence that they are applicable to the physiological, psychological, and cognitive processes of interest here could perhaps be adduced but is unavailable.

Another major issue is the development of data sets. Can "method acting" (or any other school of acting) provide sufficient verisimilitude on all scales, including emotive/biochemical (sweat, breath, body habitus, kinesiology) to permit its use as a surrogate for "real" data? If so, the creation of data sets, while still expensive, will be less expensive. If enacted experiments cannot provide data that matches data of "real" situations, the expense and uncertainty will be larger. It is often expensive and difficult to obtain large amounts of data on "real" situations. The ground truth, i.e., the true intent of the subject, may be difficult to determine because of deception or disappearance of the subject. The virtual reality community has a well-established database for determining participant engagement; this database should be explored for its applicability here. Again, a primary concern is authenticity of the data gathered when the input is produced by acting.

An alternative is to examine the principles of immersive game system design and human games. Automatic detection of adversarial intent can benefit from using methods that human experts use, including, but not limited to, criminological strategies of presenting photos of a crime scene, presenting mug shot albums, exposing subjects to news clips or headline news, filling out surveys or forms, and delaying forward movement. There is, however, an open question about whether such expertise is transferable without extensive personal immersion within a conflict environment. Also, whether these can be adapted for the desired scenario (3–50-m distance) will need to be examined.

The difficulty in obtaining ground truth for adversarial intent detection is an issue. The occurrence of adversarial intent, less than 1/1000, is also an issue. This makes a non-normative approach to statistics important. Each individual may have unique responses relevant to his or her adversarial intent. Are there special populations that can be ethically tapped to provide appropriate cognitive or psychological constructs? Can incentives provide the amount of "buy-in" needed for a valid proxy of a "bad guy?" Since we don't know what a "real bad guy" with adversarial intent may be like, perhaps we need to know in exquisite depth what a good guy looks like.

3.2 Sensing

Individuals with adversarial intent will experience physiological changes and possibly display altered motions and behaviors that may be detected. In this section, we discuss physics-based sensors that may be able to remotely detect indicators for subsequent fusion to determine intent. Physics-based sensors will provide the input for a cognitive approach to sensing adversarial intent and offer the advantage of a quantitative assessment.

The goal is to identify measureable physiological, biochemical, genetic, or other types of indicators that are correlated with an underlying elevated level of stress; a determination to carry out a plan with adversarial consequences and other less temporal predictors of violent activity including, but not limited to, social disconnectedness; and an embracing or acceptance of violence and death. Psychological, physiological, genetic, and biochemical factors that can correlate with social disconnectivity and a willingness to commit violence include aggression, impulsivity, autism, post-traumatic stress disorder (PTSD), unattractiveness, variants of chromosomal copy number, and mutations in specific genes.

Informative biological parameters that can be measured include the following:

- Posture
- Posture rigidity
- Heartbeat waveform
- Heart rate
- Breath rate, volume approximation, patterns, anomalies
- Wheezing, coughing, gasping
- Blood pressure trends: waveform shape and transit time
- Pulse-wave velocity giving a beat-by-beat approximation of blood pressure
- Movement: fidgeting, remaining still, shaking, shivering, having spasms
- Body stiffness, muscle tension, resonant frequency of body movement
- Voice stress analysis and voice onset timing
- Gastrointestinal distress, bowel sounds
- Reluctance to engage socially: distance from others, response to attempts to engage verbally
- Observation tendencies of subject, eye-glancing, head turning, situational awareness
- People whose actions are coordinated or who are actively avoiding each other
- Exposure to bomb-making materials/chemicals
- Hyperthermia from stress (generally expressed in the face, palms of the hands, and soles of the feet)
- Gait as indicators of stiffness (stress) or carrying a load or wearing protective clothing
- Breath biochemistry
- Microbiological organisms on skin or clothing

Attention should also be given to screening people in vehicles. Some potential informative and measureable signals include the following:

- Body and movement rigidity/stiffness as a measure of stress, probably more informative if measured in response to unexpected perturbation such as a unusual speed bump, unexpected timing of red light, provocative noise, or other stressor
- Acoustic signals: If one can hear what is being said or happening in the vehicle, are the occupants making small talk, silent, listening to the radio, or praying?
- Lip and facial movements: Are the occupants talking, praying, silent, listening to the radio, or listening for outside cues?

Body-contacting sensors that assess human physiology, such as those used for polygraphy, biometric identification and medical diagnosis, are common. However, using these sensors at stand-off distances presents both physics-based and operational hurdles. Many of the current sensors cannot operate at even modest distances (1 m) away from human bodies. Ongoing R&D is dramatically increasing sensor sensitivity, bandwidth, field of regard, and many other characteristics but still may not be able to overcome many of the technical barriers associated with remote intent assessment. Many of the sensors mentioned in this section may not be ready for immediate application but may offer significant benefits if sensor system maturity advances quickly.

We attempt to highlight sensing technologies that we believe can measure useful data for assessing adversarial intent. Passive and active sensors can be used to remotely characterize a human's physical features, clothing and equipment, and their interaction with the immediate surrounding environment. Passive sensors do not emit a signal and rely on a target's emission in some sensing domain. Active sensors emit a signal that interacts with the target in a known manner to produce a return that is quantifiable and related to the stimulus. Sensor fusion can combine multiple inputs and domains to enhance features and remove noise or interferers. Redundancy of diverse sensor modalities will help corroborate physiological parameters in noise as well as alternative inputs for fusion algorithms. Some potential sensor domains and expected contributions are as follows:

- Imagers, in general: Imagers with related image-processing hardware and software can assess shape and contrast and change in single images and multiple frames. Change detection algorithms detect, track, and/or assess movements and establish "normal" traits, gait, movement tracking, surveillance activity, facial expression, emotion, phenotypic patterns, and body language. Imagers provide data for extracting behaviors and interactions among people in the field of view through pattern recognition. All of these capabilities can be implemented using thermal, hyperspectral, visible, and narrowband imagery.
- Thermal imagers: Passive thermal imagery can monitor overall surface temperature patterns, radiometric levels, facial thermal patterns, capillary dilation effects, bombs/weapons, clothing thickness, and specific body features.

- Hyperspectral imagers: Passive multiband imagers are optimized to select specific wavelengths of interest related to particular optical phenomena or material. Narrowband imagery can focus on sweat, subsurface blood-flow, and particular types of clothing or equipment.
- Visible bandwidth imagers: These imagers establish "normal" visible appearance, identifiable traits for biometric ID, facial expressions, skin-tone changes, phenotypic patterns, and body language.
- Laser Doppler vibrometry: Active laser interrogation of skin or body surfaces reveals vibrational cues related to heartbeats, breaths, body resonances, muscle stiffness, voice, and voice stress.
- E-Field: Passive free-space electrodes (capacitively coupled) can detect electrical activity of the heart, brain, muscles, and hidden electronic devices.
- Radar: Active radar can detect and track human gait, heartbeats, breaths, radar cross section (RCS), and arm/leg movements.
- Ladar: Active laser radar produces 3D imagery related to "hostile" stance, 3D posture, gait dynamics, facial recognition, carrying of backpacks, and unnatural frame proportions.
- Gas chromatography: Active collection of exhaled gas, such as through a suction tube near a microphone or portal, can provide a sample for trace gas analysis, chemical emission, odor, genetic material, and biochemistry assessment.
- Genetics of prokaryotic microorganisms: Genetic mutation of prokaryotic microorganisms on or in humans is environmentally influenced. DNA mutates in prokaryotes at a rate of approximately 1 in 300 nucleotides per generation; generations can be as short as 10 min. If the mutation patterns were untangled, the resulting information could reveal where the organism has been and what it has been exposed to. Mutation and mutation rates of prokaryotic organisms on or in humans might thus help determine where humans have recently been, what they have been eating, whether they have had unusual exposures to man-made or other toxins or mutagens and, in general, whether the patterns in their microorganisms' DNA is consistent with their purported history, identity, and activities. In addition, the relative fitness of different species of prokaryotes depends on the environment; the environment of prokaryotes growing in or on humans is influenced by that human's activity. The relative abundance of different species of prokaryotes on humans is also reflective of that human's environment and could be exploited to reveal information about that person's activities.
- Chemical Sensors: Laser-induced fluorescence, i.e., active laser illumination with passive response monitoring (either fluorescent imaging or non-imaging amplitude of a particular wavelength), can be used to inspect a portion of the body for sweat or other compounds (salivary amylase or cortisol in the mouth or in the breath). Laser-induced fluorescence, laser-induced breakdown spectroscopy (LIBS), and Raman spectroscopy can be used to inspect body and clothing for traces of explosive chemicals.
- Photoacoustics: Active laser stimulation of a test area and acoustic analysis of induced resonance can give indications of trace gas from the mouth, biological markers, and chemical residue on skin.
- Retroreflection: Active laser illumination and passive imaging of the collimated returns can be used for detection of optics/video cameras used by a target and can also detect naked eyes in close proximity for staring or eye tracking.
- Seismic: Passive sensing of ground or floor vibrations can be used to assess gait anomalies from concealed objects and weight anomalies and for motion tracking. Active stimulation can induce movement of hidden objects.
- Magnetics: Passive magnetic sensing can detect hidden objects that might indicate intent, such as a pistol, knife, or explosive initiator component.

On a slightly higher level, one could measure the following:

- Physical evidence of psychological traits: Physical evidence of psychological traits of interest (PTSD, autism, antisocial behavior, embracing violence, indifference to human death, etc.) could be measured. One would have to develop an enabling database for phenotypic-to-psychological correlation.

Operational considerations include covertness of stand-off sensing, amount of clothing that might mask measureable parameters, interfering signals from motion artifacts, environmental considerations, ambient noise, speech, and the dynamic movement of the subject or sensor system. If a particular assessment on an individual requires a comparison with some preexisting "baseline," a plan needs to be established to access the baseline in the operational environments being discussed. An obvious objective is to process the data in real time to show states and changes in measured parameters. However, there may be a requirement to log raw data for post-processing for complex analysis of high-bandwidth imagery or multichannel fusion.

3.3 Information Fusion

Remote human detection with high classification and determination of intent over ranges up to 50 m is a challenging task. Humans engaged in planning a threat carefully plan their mission, rehearse, and take precautionary measures to hide and disguise their intention as a normal event. Passive measurement of observable physical items (gait, arm swings, and posture—carrying a heavy load might alter the way a human walks) or a vehicle (determining the weight it is carrying—abnormal RPMs) can be accomplished. In addition, one can introduce a stimulus that generates an element of surprise that alters the rehearsed plan of action. A human might, in response, conduct unrehearsed sudden irregular motion. Such behaviors may help differentiate threats from non-threats when fused with other "orthogonal" information from other sensing modalities.

The Joint Directors of Laboratories (JDL) Data Fusion Model is the most widely used method for categorizing information fusion-related functions [4]. The information fusion process involves combining information—in the broadest sense—to estimate or predict the state of some aspect of the universe. Although there are many criticisms of the JDL model and many competing models, the JDL model has, in general, withstood the test of time. Most of the fusion community has accepted the JDL fusion levels. There are frameworks that extend and more practically functionalize the JDL fusion model. An example is the Contextual Fusion Model [3,4], which includes context and handles input derived from both hard and soft sensors in addition to producing a more specific functionalization of the desired fusion process for implementation.

Here, we include consideration of informational and cognitive/perceptual states and physical states that were not the main focus of the original JDL model. The extent to which the JDL model can be extended to informational and cognitive/perceptual states is not yet known. The answer to this question hinges, in part, on issues such as representation of uncertainty that were not previously considered. In the next paragraph, we describe the issues related to representation of uncertainty as they are now appearing in the context of information fusion.

There is a question about whether and to what extent classical probability theory (typically, Bayesian theory) is applicable for fusion processes involving cognitive phenomena. There is wide agreement that information from physical sensors can be assessed and fused using classical probability measures. When cognitive phenomena are considered, however, other representations of uncertainty, ones less dependent on statistical assumptions and more able to handle data of varying types and sparse data, may be needed. Consider the information processing at the cognitive level as a system of subsystems (i.e., local processing in physical devices, information fusion in the network, etc.). Uncertainty is propagated upwards. Uncertainty may be in the form of the pedigree of information, degraded sensing, digital communications degradation/collisions, etc. As these uncertainties are propagated upwards, the performance of the higher-level system may be adversely affected. It is possible that the higher-level uncertainties will not be described appropriately by probabilities (which might have been inappropriately "summed" in prior efforts). There are many alternatives to classical probabilistic (often Bayesian) methods. Dezert-Smarandache theory has had success in robotics, and the Dempster-Shafer theory has been applied in many areas and has been useful for "real-life" problems. The Transferable-Belief Model (TBM) has been successfully used in marketing, and Analysis of Competing Hypotheses (ACH) has been used in human intelligence. All of these methods have had success in additional areas. Possibility theory is also a candidate for assessing propagated uncertainties. Bossé et al. [7] discuss various methods for representing uncertainty in fusion processes.

The emphasis here has been on the fusion of information from physics-based sensors because such fusion is currently not yet feasible and designing it is a huge task in itself. In future operations, all-source fusion ("hard/soft fusion"), where the input comes from all available sources (physical sensors, informational resources, human reports, etc.), will certainly be required. In all types of fusion, the choice of the representation of uncertainty needs to be coordinated with the fundamental science of the phenomena.

4 Coordination

The infrastructure for R&D for remote detection of adversarial intent is already in place in academia, government laboratories, and industry. The way in which researchers and developers in various disciplines and organizations collaborate to pursue larger goals will be a large factor in determining the rapidity with which R&D is accomplished. Research in remote detection of adversarial intent involves cognitive science, psychology, physiology, and behavioral science. Relevant areas include clinical psychology, cognitive neuroscience, communications, computer and information science, criminal science, decision science, developmental psychology, ethics, geography, human cognition, industrial organization psychology, linguistics and computational linguistics, perception psychology, physical and cultural anthropology, psychophysiological psychology, risk and risk management, social psychology, and sociology.

4.1 Balance between Near-Term Development and Long-Term Research

In any long-term research project, there is a multitude of near-term issues that impact the conduct of research. On occasion, these near-term issues could hinder progress toward long-term solutions. At other times, the near-term issues aid progress toward long-term solutions by drawing attention to unforeseen problems that, if recognized and investigated early on, significantly shorten the path to the long-term goal. The options of focusing exclusively on long-term research without recognizing the importance of near-term issues and focusing only on near-term issues without cognizance of the need for long-term research are both less than optimal. Government, societal, and scientific needs require that near-term benefits and long-term goals be balanced against each other.

The traditional technology transfer paradigm of scientists, engineers, and mathematicians making basic discoveries in their research and passing them on to development personnel for implementation is no longer the only or best option for R&D. Increasingly, researchers are being called upon to interact and collaborate with development personnel to reduce the time necessary to build operational systems. It is in a framework of two-way technical collaboration between basic researchers and development personnel that issues impacting long-term development of a system can be identified earliest and solved most efficiently. A successful basic research program on remote detection of covert tactical adversarial intent of individuals in asymmetric operations will be a set of interdependent projects linked interactively with development programs. The urgency of the need suggests strongly that applied R&D needs to begin before basic research is complete. In addition, applied R&D will likely generate “real data” on its way to developing specific systems and will thereby benefit basic research, which currently has very little access to “real data” and consequently is hampered in the development of relevant theory. Traditionally, basic research has been achieved either by chance or because of a demonstrated need over a long period of time. There is currently a great need to carry out basic research and applied R&D hand-in-hand so that the entire problem is solved and the time taken to produce a deployable solution is shortened.

4.2 Collaboration among Government, Academia, and Industry

Currently, there are many efforts in and bordering on the areas discussed in Section 3. These efforts are supported by many different agencies and coordinated through formal and informal meetings of investigators at working groups, conferences, and other events. Some of these efforts by DHS, ARL/HRED, ARL/ARO, NVESD, AFRL, NRL, AFOSR, and IARPA are mentioned in the Introduction. These and future efforts in the area described in this paper are being coordinated among interested agencies with the objective of creating connected, complementary projects that accelerate the research overall. Consistent with the approach mentioned in Subsection 4.1, these efforts contain interconnected basic research, applied research, and development components.

5 A Path to the Future

In the article, we have summarized the state of the art in remote detection of adversarial intent and have pointed out the need for coordinating R&D in many dimensions, including 1) cognitive/perceptual phenomena, sensing, and information fusion, 2) near-term development and long-term research, and 3) different types of organizations (government, academia, industry). The U.S. Government expects to support R&D programs with the objective of producing theoretically founded designs of a prototype system for remote detection of covert tactical adversarial intent of individuals in asymmetric operations. The Government also expects to provide broad support for academic and industrial efforts in remote detection of adversarial intent and in areas (such as linkage of these systems with databases, media, and human input) that are useful for larger systems of systems. Other governments have expressed similar plans. Research on winning the hearts and minds of populations could pay off well in reducing the occurrence of adversarial intent [8,9]. The reduction will, however, never be zero, and the research described in this paper will always be needed.

Dual uses of remote detection of adversarial intent in the civilian economy include crowd control, antidrug and anticrime operations, border security, and ensuring the security of government and private personnel and property.

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